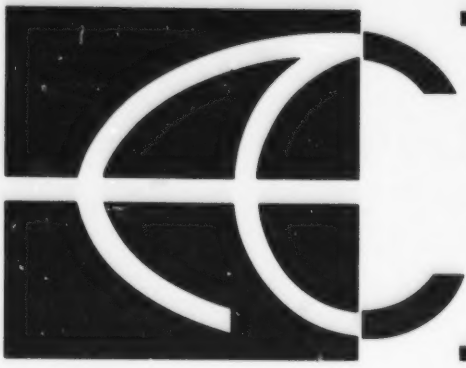

AGRICULTURAL ENERGY CENTRE

CURING AND STORING SWEET POTATOES

IN A MODIFIED BULK TOBACCO KILN

Report No. 88-5102 January, 1988

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By:

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ABSTRACT

A bulk tobacco kiln was modified to cure and store 11.4 tonnes of "Ontario grown" sweet potatoes. The blower/burner unit of the bulk tobacco kiln was not utilized. Instead, a 4.8 kW heater and a fan rated at 900 L/s @ 90 Pa were used to provide heat and aeration, respectively. The insulation value of the kiln's roof was upgraded to 4.7 RSI to prevent condensed moisture from dripping on the sweet potatoes during curing and storage. Curing conditions used were 26 to 30°C @ 88 to 96% relative humidity, while storage conditions used were 13 to 14°C @ 81 to 92% relative humidity. After 7.7 days of curing and 41 days of storage the sweet potatoes lost an average of 8.6% of their weight. Energy consumption was about 910 kWh for curing and 1010 kWh for storage. Marketed quality was considered excellent.

BACKGROUND INFORMATION

A decline in the demand for Ontario flue-cured tobacco has prompted some tobacco producers to diversify into other crops. A wide range of crops exist which can be grown on the sandy soils of the tobacco belt, however, many of the crops require curing and/or storage. Tobacco growers often do not have the financial resources to purchase conventional curing and/or storage facilities. Many growers are reducing their initial diversification costs by utilizing existing tobacco structures for crop curing and/or storage.

Since 1982, the Agricultural Energy Centre of the Ontario Ministry of Agriculture and Food has been investigating the applicability of utilizing tobacco kilns to cure and/or store crops such as peanuts and shelled corn. On-farm demonstrations have indicated that both of these crops can be successfully cured and stored in bulk tobacco kilns. However, before any recommendations can be made proper curing and storage conditions must be known and appropriate kiln modifications must be determined.

On-farm demonstrations have provided valuable information to tobacco producers making the transition to other crops. However, as more tobacco producers diversify, there is a need to continue investigation of utilizing existing tobacco structures for additional crops.

One such crop is sweet potatoes (Ipomoea batatas). The sweet potato is a member of the Convolvulaceae or morning-glory family. The sweet potato is a perennial, however, in the United States it is grown as an annual because of the killing cold during the winter months.

The sweet potato is not a new crop to Southern Ontario. During the 1940's sweet potatoes were grown in southwestern Ontario for the canning industry. After the '40's interest in sweet potatoes declined because of growth in the tobacco

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The mention of manufacturer's trade names is for the purpose of specific product description and does not indicate endorsement or criticism of that product or products not mentioned by the author or the Ontario Ministry of Agriculture and Food.

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industry. It was not until this past year that interest in growing sweet potatoes was renewed. In 1987, approximately 12 hectares of sweet potatoes were grown on a trial basis by an association of about 35 growers in the Delhi - Simcoe area.

Robert Townsend, a member of the sweet potato association approached the Agricultural Energy Centre regarding the possibility of curing and storing sweet potatoes in bulk tobacco kilns. Earlier research conducted in Ontario during the '70's indicates that tobacco kilns can be used for curing and storing sweet potatoes (Collin, 1981). Collin indicated that installation of a vapour barrier and upgrading the insulation of a kiln are two requirements. The vapour barrier reduces moisture escape from the kiln, while the insulation reduces the heating load and allows a consistent curing or storage temperature to be attained. Collin (1981) did not indicate if any additional modifications are required or if the quality of sweet potatoes cured and stored in tobacco kilns is comparable to conventional methods. Thus, a project was initiated to utilize a bulk tobacco kiln (at the farm of Robert Townsend) to cure and store "Ontario grown" sweet potatoes.

LITERATURE REVIEW

Curing

Sweet potatoes must be cured if they are to be stored for any length of time. Curing decreases the possibility of decay (such as "soft rot") during storage by promoting the healing of cuts, bruises and skinned areas caused by harvesting and handling. In addition, curing permits a starch to sugar conversion to occur which enhances the cooking quality of the sweet potatoes (Covington et al, 1976).

Curing should begin almost immediately after digging. Optimum curing conditions are: dry-bulb temperature of 30°C; relative humidity of 90 to 95%; continuous air circulation; and sufficient air exchange (Wilson and Abrams, 1982).

Continuous air circulation distributes heat uniformily and prevents any heat buildup in the top of the curing structure. Air circulation also assists in the evaporation of water added to the curing structure to maintain high humidity levels. Suggested air circulation rates are 30 to 42 L/s per tonne of sweet potatoes (Covington et al, 1976).

Sweet potatoes absorb O_2 and respire CO_2. Air exchange will replenish O_2 and decrease the CO_2 concentration. In addition, air exchange removes any excess heat and moisture accumulation. Minimum air exchange requirements for gas control are in the order of 0.4 L/s per tonne of sweet potatoes during storage (ASAE Monograph, 1983). It is suspected that air exchange requirements are greater for curing, however, no literature could be cited to verify this assumption.

The length of time required for curing can range from 4 to 10 days. Curing is complete when cuts and skinned areas have healed. Another indication that curing is complete is when the roots produce a few short sprouts (Steinbauer and Kushman, 1971). Cured sweet potatoes can loose up to 5% of their original weight because of water loss from evaporation and dry matter loss from respiratory oxidation of sugars (Steinbauer and Kushman, 1971).

Storage

Optimum storage conditions are 13°C at 85 to 90% relative humidity and sufficient aeration (Wilson and Abrams, 1982). The air circulation rate is similar to that used during curing. Air exchange requirements are in the order of 0.4 L/s per tonne of sweet potatoes. A weight loss of 15% during a 5 month storage period is not uncommon (Steinbauer and Kushman, 1971).

Utilizing Tobacco Kilns for Curing and Storing Sweet Potatoes

Watkins and Wilson (1977) reported that tobacco bulk barns in North Carolina (in Ontario referred to as tobacco bulk kilns) are being utilized for curing and storing sweet potatoes, however, it is not highly recommended. Before any degree of curing and storage success can be attained, modifications are required to the kiln's structure and blower/burner unit.

Bulk tobacco kilns are equipped with blower/burner units which are over-sized for curing and storing sweet potatoes.

Using the existing blower/burner arrangement results in excessive weight loss from dehydration and unwarranted energy costs. Other negative aspects of utilizing bulk tobacco kilns is their "loose" structure and poor insulation values. A "tight" structure is required to maintain high humidity levels, while proper insulation values will prevent condensation from forming and reduce heat loss.

Watkins and Wilson (1977) recommended that if bulk tobacco kilns are utilized for sweet potato curing and storage, the follcwing kiln modifications are necessary:

- reduce the heat output of the burner to 100 MJ/h
- decrease the pulley size on the motor powering the blower and decrease the motor size
- operate the blower/burner intermittently during curing and storage
- upgrade insulation values
- install a fan (700 L/s @ 30 Pa)/motor arrangement above the sweet potatoes to provide ventilation above the sweet potatoes when no heat is added to the structure

Modifying bulk tobacco kilns in the above-mentioned manner prevents:

- excessive aeration during curing and storage
- excessive moisture loss
- heat loss
- heat accumulation in the top of the kiln
- excessive energy consumption

PROJECT OBJECTIVES

The applicability of utilizing bulk tobacco kilns to cure and store sweet potatoes will be determined by:

1) kiln modifications;
2) cost of kiln modifications;
3) handling requirements;
4) energy consumption;
5) sweet potato quality after curing and storage.

METHODS AND SELECTION

Site and Kiln Selection

A test site was selected at the farm of Robert Townsend, R. R. # 5, Vanessa. The farm is equipped with "DeCloet" bulk tobacco kilns fuelled by natural gas. Each kiln is equipped with: fourteen and a half curing bins; a 380 MJ/h burner; and a "Delhi Industries", model 925, centrifugal blower powered by a 5.6 kW motor. The insulation values of the kiln walls and roof were 2.1 RSI and 1.0 RSI, respectively. A poly vapour barrier lines the entire interior (beneath aspenite) of the kiln walls. Each kiln is situated on a concrete pad.

System Design

Based on the literature reviewed and past experience with bulk tobacco kiln projects (tobacco curing related), it was decided that the blower/burner unit of a "DeCloet" kiln is excessively oversized for this particular application. The blower rated at 7000 L/s @ 485 Pa at 560 r.p.m. was selected for curing tobacco not sweet potatoes. Decreasing the r.p.m. of the fan would decrease the airflow, however, it is not a practical or efficient solution. Since the cooperator anticipated that no more than 22 tonnes of sweet potatoes would be cured and stored in one bulk tobacco kiln, a fan capable of providing 920 L/s @ 90 Pa would be sufficient.

A "Delhi Industries", model 412, centrifugal fan was selected as the air recirculator. Operating at 780 r.p.m. the fan would provide 900 L/s @ 90 Pa. A 0.75 kW motor was selected as the power source. As illustrated in Figure I, the inlet of the fan was connected to a circular opening (35 cm in diameter) cut into the side of the existing blower shroud. A 34 cm x 23 cm opening was cut in the plywood floor to accommodate the outlet of the fan. With this arrangement the air within the kiln would be circulated in the same manner as during tobacco curing. Air would be pushed up through the perforated floor, through the sweet potatoes and return to the return air inlet of the existing blower/burner unit. The additional fan was installed in this manner so that the cooperator could continue

to use the bulk kiln for curing tobacco prior to sweet potato harvest.

Air exchange would be accomplished by opening the fresh air intake dampers of the existing blower/burner unit. Fresh air would be drawn into the kiln to replenish the O_2 supply and positively pressurize the kiln. Air containing high levels of CO_2 or excess heat would be expelled through pressure sensitive louvres located above the loading doors of the bulk kiln.

As illustrated in Figure II, a false ceiling was installed below the roof of the kiln. It extended from the middle of the curing compartment to the return air inlet of the existing blower/burner unit. The false ceiling served as the bottom portion of an air duct. The outside walls and roof of the kiln served as the sides and top of the air duct, respectively. The purpose of the duct was to collect air centrally in the kiln after it has passed through the sweet potatoes. The air would then return to the return air inlet of the existing blower/burner and be recirculated through the sweet potatoes. This would prevent the lowered volume of air from short-circuiting through the sweet potatoes at the blower/burner end of the kiln.

The insulation value of the kiln roof was upgraded, since there was a possibility that some of the sweet potatoes would not be marketed until January or February. Condensation and heat loss were prime concerns. During January and February below freezing temperatures are common and upgrading the roof's 1.0 RSI value would be necessary to prevent condensed moisture from dripping on the sweet potatoes. A 90 mm application of urethane foam was applied to the underside of the roof to raise its RSI value to 4.7. As calculated in Appendix I, a storage temperature of 13°C and 90% relative humidity would have a dew point of 12°C and upgrading the RSI value to 4.7 would prevent condensation forming at an outside temperature of -18°C (minimum design temperature for area) or warmer. Upgrading the insulation value of the walls was considered, however, condensation forming on the walls would not drip directly on the sweet potatoes and it was felt the additional cost to upgrade the insulation value was not warranted.

Sizing the heater required for curing and storage was determined by calculating: 1) conductive heat loss through the structure of the kiln; 2) heat loss through air exchange; and 3) heat gain from respiration of the sweet potatoes. As calculated in Appendix II, 22 tonnes of sweet potatoes stored at 13°C during -18°C weather, would require 1.95 kW of heat to maintain the storage temperature. If only 11 tonnes of sweet potatoes were stored under the same conditions 2.41 kW would be required. (The existing burner of the bulk kiln rated at 106 kW was excessively oversized.) Based on the heating calculations, a 4.8 kW electric fan-forced heater was selected. The heater was positioned on the flame deflector of the existing burner. In this position the heat source was in the circulating air path.

The blower was operated continuously and the heater was controlled by a thermostat and electronic relay. The sensing element of the thermostat was positioned on the perforated floor (below the sweet potatoes) in the curing/storage compartment. The thermostat would control the on/off cycling of the heater. The electronic relay would prevent the heater from operating without the fan operating.

Raising or lowering the relative humidity level during curing and storage would be accomplished manually. A relative humidity greater than 90% would be reduced by opening the fresh air intake dampers of the existing blower/burner unit. If the relative humidity is 90% or lower the dampers would remain open only enough for air exchange requirements. Increasing the relative humidity to 90% would be accomplished by adding water (via a garden hose) on the concrete pad below the kiln floor.

The costs of modifying the bulk kiln for curing and storing sweet potatoes were as follows:

-	insulation (application included)	$1135
-	fan	$ 142
-	lumber for duct	$ 38
-	relays, heater, thermostat (electrical hook-up included)	$ 554
	Total Costs	$1869*

*used 0.75 kW motor not included in cost.

MONITORING

During curing and storage various dry-and wet-bulb temperatures were recorded at 1.0 h intervals using type T thermocouples connected to a "Kaye Digistrip III" datalogger. The following temperatures were recorded:

- dry-bulb temperature below sweet potatoes (4 locations)
- aspirated wet-bulb temperature below sweet potatoes (1 location)
- dry-bulb temperature in middle of sweet potato layer (3 locations)
- dry-bulb temperature above sweet potatoes (3 locations)
- aspirated wet-bulb temperature above sweet potatoes (1 location)
- ambient dry-and wet-bulb (aspirated) temperature (1 location)

The electrical consumption of the fan motor and heater were monitored with separate kWh meters. The sweet potatoes were weighed prior to kiln loading. Individual sample lots were also weighed. After curing and storage the sweet potatoes were weighed again to determine the % weight loss resulting from curing and storage.

EVALUATION AND RESULTS

Grading and Handling

Seven varieties* of sweet potatoes were harvested from 0.56 ha on September 26 and 27. The sweet potatoes were graded visually into three grades: 1) jumbo - diameter greater than 90 mm and/or length greater than 230 mm; 2) No. 1 - diameter 50 - 90 mm and length 75 - 230 mm; and 3) canners, culls and cracks - diameter less than 50 mm and length less than 180 mm and/or misshapened or cracked. During grading the sweet potatoes were loaded into slotted wooden/wire crates with dimensions of 330 mm (w) x 480 mm (l) x 280 mm (h). (The crates

had been previously used for transporting tomato transplants from Georgia). As illustrated in Figure III, the crates were loaded into tobacco curing bins. Each bin was then rolled into the bulk tobacco kiln. Each full-size bin contained 40 - 50 crates, while the single half-bin contained 20 crates. In total, 603 crates of mixed varieties and grades representing a total weight of 12 488 kg of sweet potatoes were loaded into the bulk tobacco kiln.

It should be noted that using the slotted wooden/wire crates for handling sweet potatoes is not recommended. The wooden/wire crates caused more surface damage (such as cuts) to the sweet potatoes than the mechanical digger. Increasing the surface damage of sweet potatoes increased the possibility of disease formation during curing.

*Varieties - Jewel, Georgia Jet, Regal, Resisto, Cordner, Topaz and Sweet Red.

Curing and Storage Log

The curing and storage log recorded by the cooperator is contained in Appendix III. Curing began on September 26, 5:30 p.m. and concluded October 4, 11:00 a.m. for a total of 185.5 h or 7.7 days. The heater thermostat setting was 30°C for the entire curing period. The amount of fresh air introduced during curing was dependent upon: temperature and relative humidity of the curing environment (recorded by the datalogger); and gas exchange requirements. A fresh air damper opening of 0.5 cm was used to control gas exchange, while damper openings greater than 0.5 cm were used to decrease the relative humidity to 90%. The curing temperature never exceeded 30°C so the dampers were never used to reduce the curing temperature.

Water evaporating from the sweet potatoes maintained the relative humidity at 90% for the majority of the time, however, on 5 occasions water was added for total time of 70 minutes (flow rate measured at 0.25 L/s). Thus, approximately 1050 L of water was added during the curing period.

Storage began on October 4, 11:00 a.m., and concluded November 14, 10:00 a.m., for a total of 983.0 h or 41 days. Two thermostat settings were used. During the initial 10 days of storage the thermostat setting was 15°C, while during the last 31 days of storage the thermostat setting was 13°C. The amount of fresh air introduced during storage was dependent upon: temperature and relative humidity of the storage environment (recorded by datalogger); and gas exchange requirements. A fresh air damper opening of 0.5 cm was used to control gas exchange, while damper openings greater than 0.5 cm were used to decrease the relative humidity to 85 to 90% or to decrease the temperature if it was greater than the thermostat setting. Water was added to the storage on 18 occasions for a total period of 315 minutes. Thus, approximately 4725 L of water was added during the storage period.

Temperatures Recorded By Datalogger

The hourly average temperatures recorded by the datalogger were accumulated per day and then averaged to reflect "daily temperatures". As illustrated in Figure IV, the average daily temperature of three locations in the kiln ranged from 21°C to 30°C during 8 days of curing. The average daily ambient (outside) temperature during the curing period ranged from 8°C to 20°C. Since curing began September 26 (day 1) and the bulk kiln was not completely full of sweet potatoes until September 27 (day 2), continual opening and closing of doors did not allow the temperature to increase until the day 3 of curing. In addition, heat was required to raise the temperature of the incoming sweet potatoes to curing temperature. From day 3 of curing until completion, the temperature ranged between 28°C to 30°C below the sweet potatoes. During the same time period the temperature in the middle of the sweet potato crates and above the sweet potatoes ranged from 26°C to 29°C.

On October 4 (day 8 of curing) at 11:00 a.m. the thermostat

setting was lowered to a storage temperature of 15°C. As illustrated in Figure V, lowering the temperature from 30°C to 15°C did not result in an immediate reduction in temperature. The temperature below the sweet potatoes did not reach 15°C until day 7 of storage. This possibly could have been avoided by increasing the amount of fresh air into the kiln, however, there was concern that the relative humidity would drop below 85%. As illustrated in Figures V and VI, from day 7 until completion of storage the temperature usually remained between 13°C to 14°C at all three locations.

Relative Humidity Recorded By Datalogger

As illustrated in Figure VII, the average daily relative humidity from day 2 of curing until completion ranged from 88% to 93% below the sweet potatoes, while above the sweet potatoes it ranged from 89% to 96%. During day 1 of curing the relative humidity at both locations was similar to the ambient relative humidity. Again, this can be attributed to continual opening and closing of doors during filling.

Figures VIII and IX illustrate the average daily relative humidity over the storage period. During the first 21 days of storage the relative humidity below the sweet potatoes dipped once to 81% on day 2, however, for the majority of time it remained relatively close to the 90%. The relative humidity above the sweet potatoes during the same period of averaged approximately 92%. The relative humidity from day 22 until the end of storage averaged approximately 88% below the sweet potatoes and 91% above the sweet potatoes.

Weight Loss

Figure X indicates the percentage weight loss of the sweet potatoes resulting from curing and storage. The smallest weight loss, 6.0%, was recorded for the jumbo grade of the Jewel variety. The greatest weight loss, 9.5%, was recorded for the mixed varieties of Cordner, Resisto, Sweet Red, Topaz and Regal.

Overall, the percentage weight loss of the entire kiln of sweet potatoes was 8.6% (initial recorded weight 12 488 kg, final recorded weight 11 418 kg).

Energy Consumption

Figure XI indicates the energy requirements for curing and storage. The 4.8 kW heater consumed 820 kWh during 185.5 h of curing, while 520 kWh were consumed during 983.0 h of storage. The 0.75 kW motor operating the blower consumed 90 kWh during curing and 490 kWh during storage. The total cost for curing amounts to $4.03/tonne ($45.96/11.418 tonne), while storage costs amount to $4.47/tonne ($51.01/11.418 tonne) with electrical energy at $0.0505/kWh.

DISCUSSION

The cooperator indicated that the sweet potatoes were of excellent quality when marketed. Overall, the sweet potatoes retained their firmness and minimal losses resulted from storage rot.

Some other sweet potato growers did not realize the same degree of success. Many indicated that it was difficult to maintain high humidity levels during curing and storage in bulk tobacco kilns. In almost every instance sweet potato growers who indicated humidity problems were utilizing the kiln's existing blower/burner arrangement and operating it continuously. Continuous operation of the blower (which is excessively over-sized for curing and storage) dehydrated the sweet potatoes. However, this should not be misinterpretted to indicate that all sweet potato growers using bulk and stick kilns were unsuccessful. Some growers with bulk kilns cycled the kiln's blower which reduced dehydration, while others using stick kilns (which have smaller blowers) were able to maintain relative humidity levels more easily. Most growers did agree, however, that kiln modifications could have improved their sweet potato quality.

SUMMARY

Project results indicate that sweet potatoes can be successfully cured and stored in modified bulk tobacco kilns. Continuous operation of a bulk tobacco kiln's blower/burner unit could result in dehydrating the sweet potatoes and possibly an unsaleable product.

Modifications are not cheap - $1869. The largest expense however was the $1135 for upgrading the RSI value of the kiln roof to prevent condensed moisture from dripping on the sweet potatoes. The degree of insulation and thus the expense could have been reduced if it was known that the sweet potatoes would be marketed in mid-November. However, marketing is dependent upon demand and it is conceivable that the sweet potatoes could have remained in storage until January or February. Thus, if only as a precautionary measure, upgrading the insulation value of the roof should not be overlooked.

ACKNOWLEDGEMENTS

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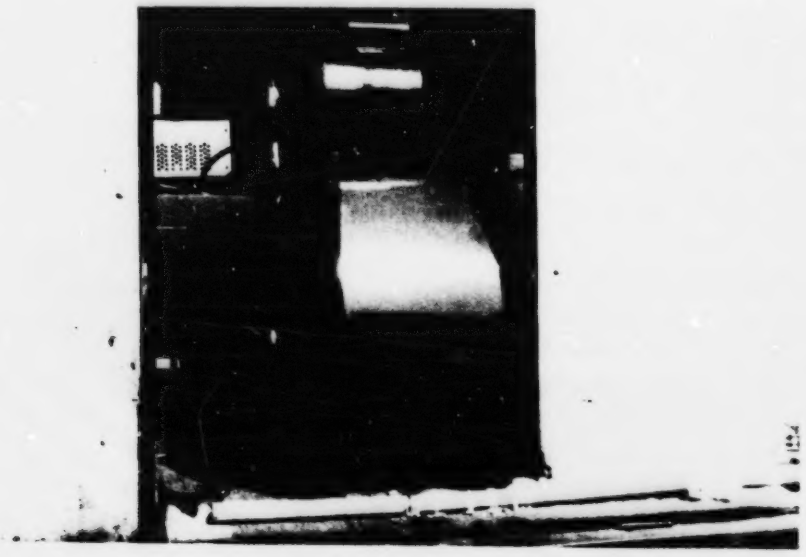

Figure I: Fan attached to side of existing blower/burner unit.

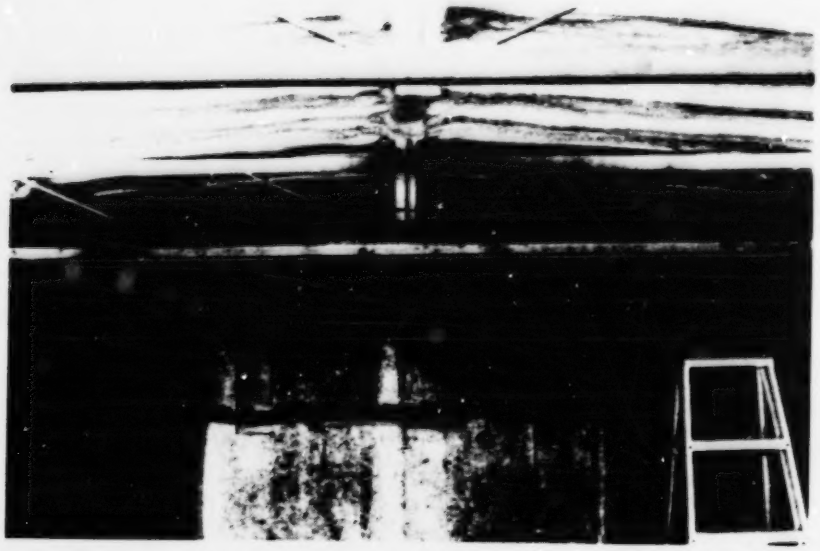

Figure II: Air duct (constructed above sweet potatoes) used to collect air after it passed through the sweet potatoes. The air would return to the blower and recirculate through the sweet potatoes.

Figure III: Slotted wooden crates containing sweet potatoes in a tobacco curing bin.

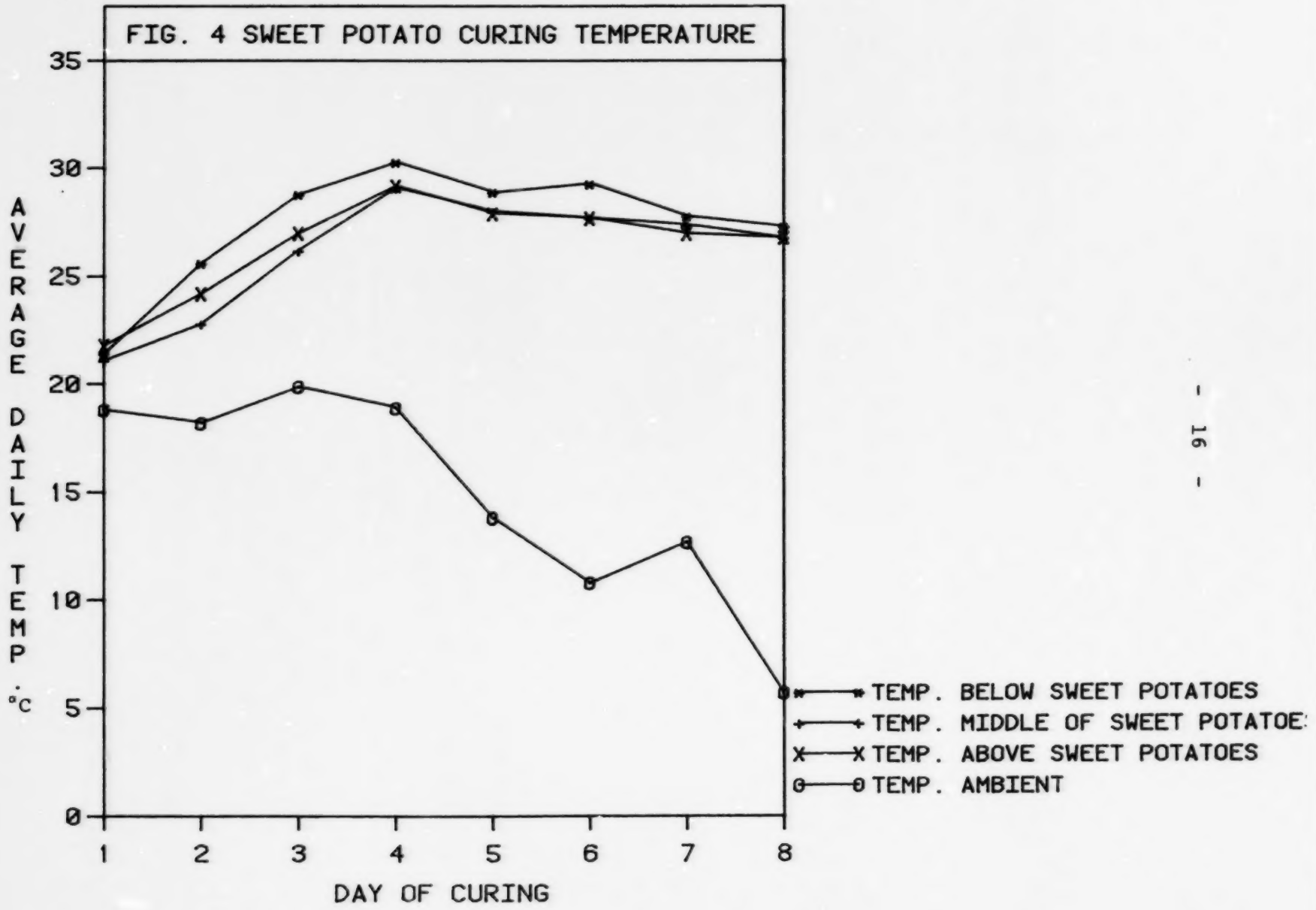
FIG. 4 SWEET POTATO CURING TEMPERATURE
AVERAGE DAILY TEMP. °C
35
30
25
20
15
10
5
0
1
2
3
4
5
6
7
8
DAY OF CURING
TEMP. BELOW SWEET POTATOES
TEMP. MIDDLE OF SWEET POTATOE
TEMP. ABOVE SWEET POTATOES
TEMP. AMBIENT

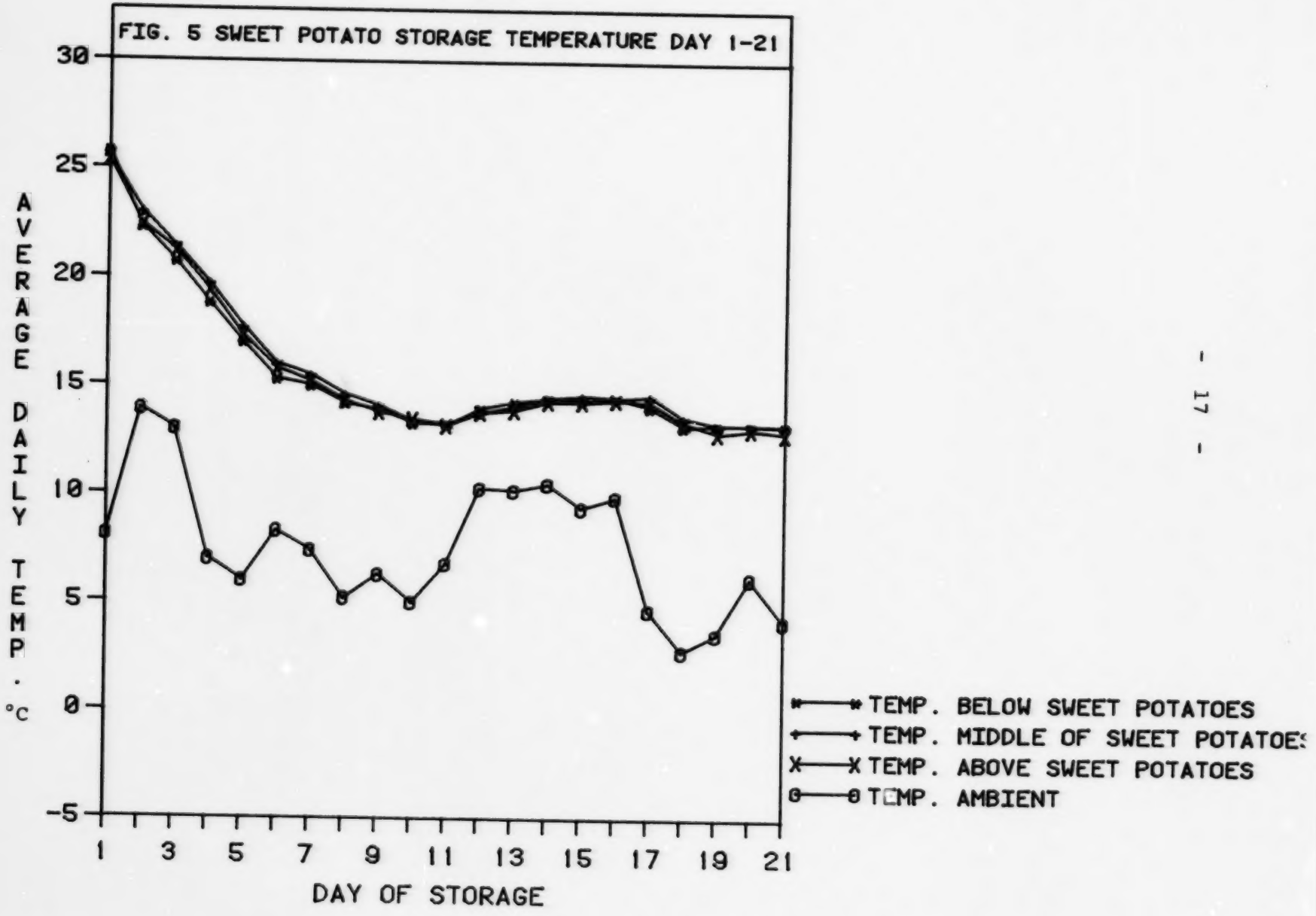
FIG. 5 SWEET POTATO STORAGE TEMPERATURE DAY 1-21
AVERAGE DAILY TEMP. °C
30
25
20
15
10
5
0
-5
1
3
5
7
9
11
13
15
17
19
21
DAY OF STORAGE
TEMP. BELOW SWEET POTATOES
TEMP. MIDDLE OF SWEET POTATOES
TEMP. ABOVE SWEET POTATOES
TEMP. AMBIENT

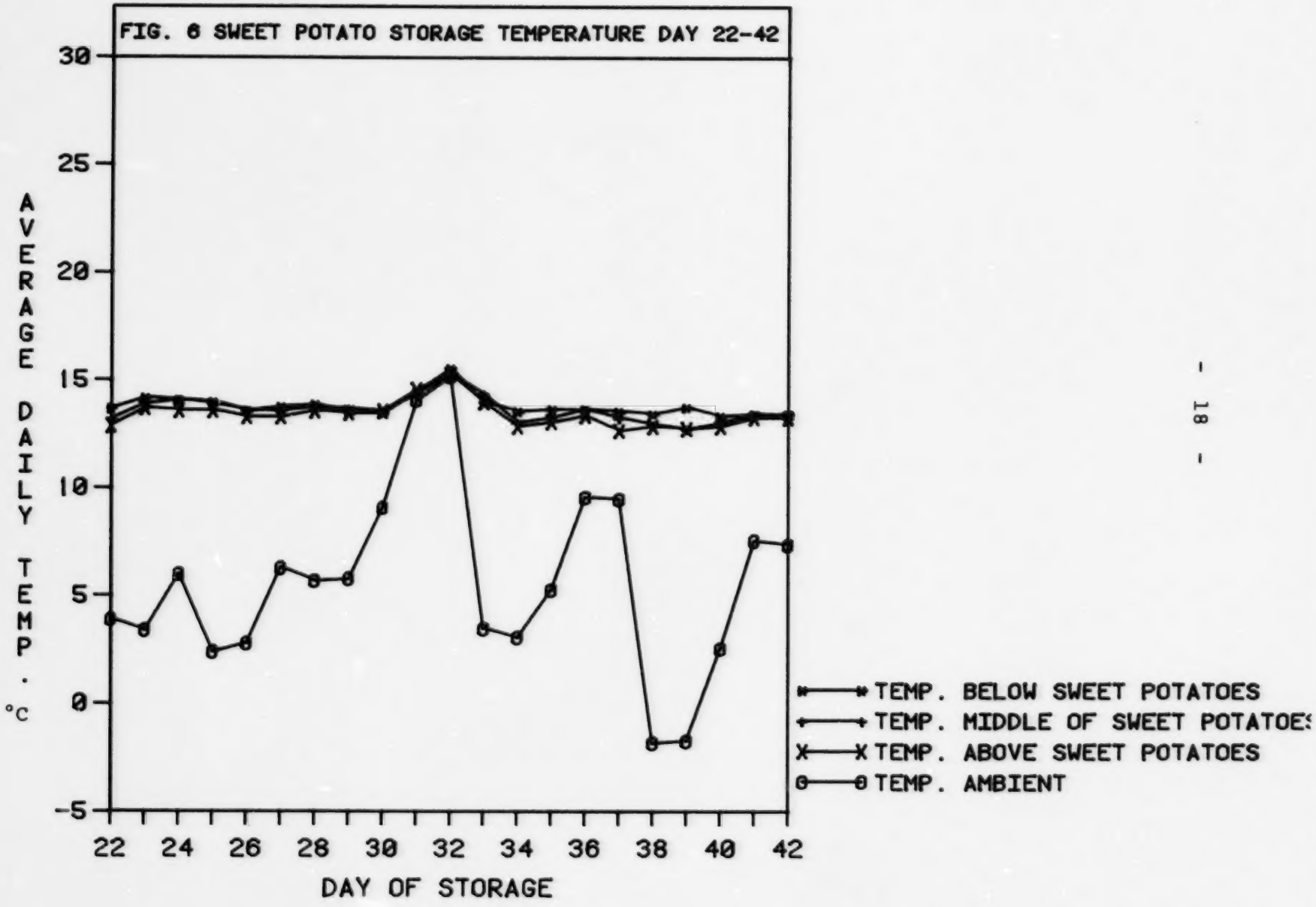
FIG. 6 SWEET POTATO STORAGE TEMPERATURE DAY 22-42
AVERAGE DAILY TEMP. °C
30
25
20
15
10
5
0
-5
22
24
26
28
30
32
34
36
38
40
42
DAY OF STORAGE
TEMP. BELOW SWEET POTATOES
TEMP. MIDDLE OF SWEET POTATOES
TEMP. ABOVE SWEET POTATOES
TEMP. AMBIENT

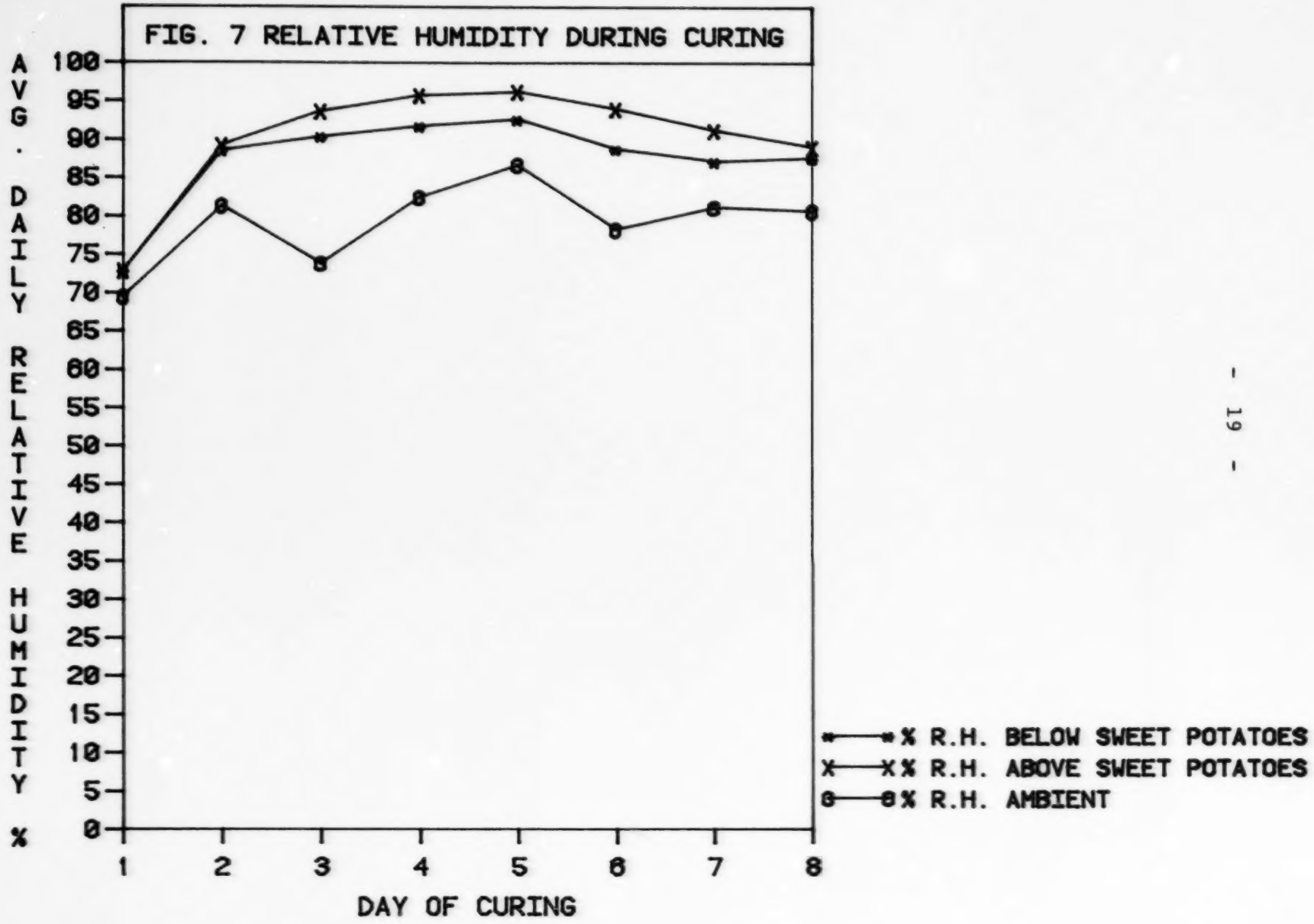
FIG. 7 RELATIVE HUMIDITY DURING CURING
AVG. DAILY RELATIVE HUMIDITY %
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
1
2
3
4
5
6
7
8
DAY OF CURING
% R.H. BELOW SWEET POTATOES
% R.H. ABOVE SWEET POTATOES
% R.H. AMBIENT

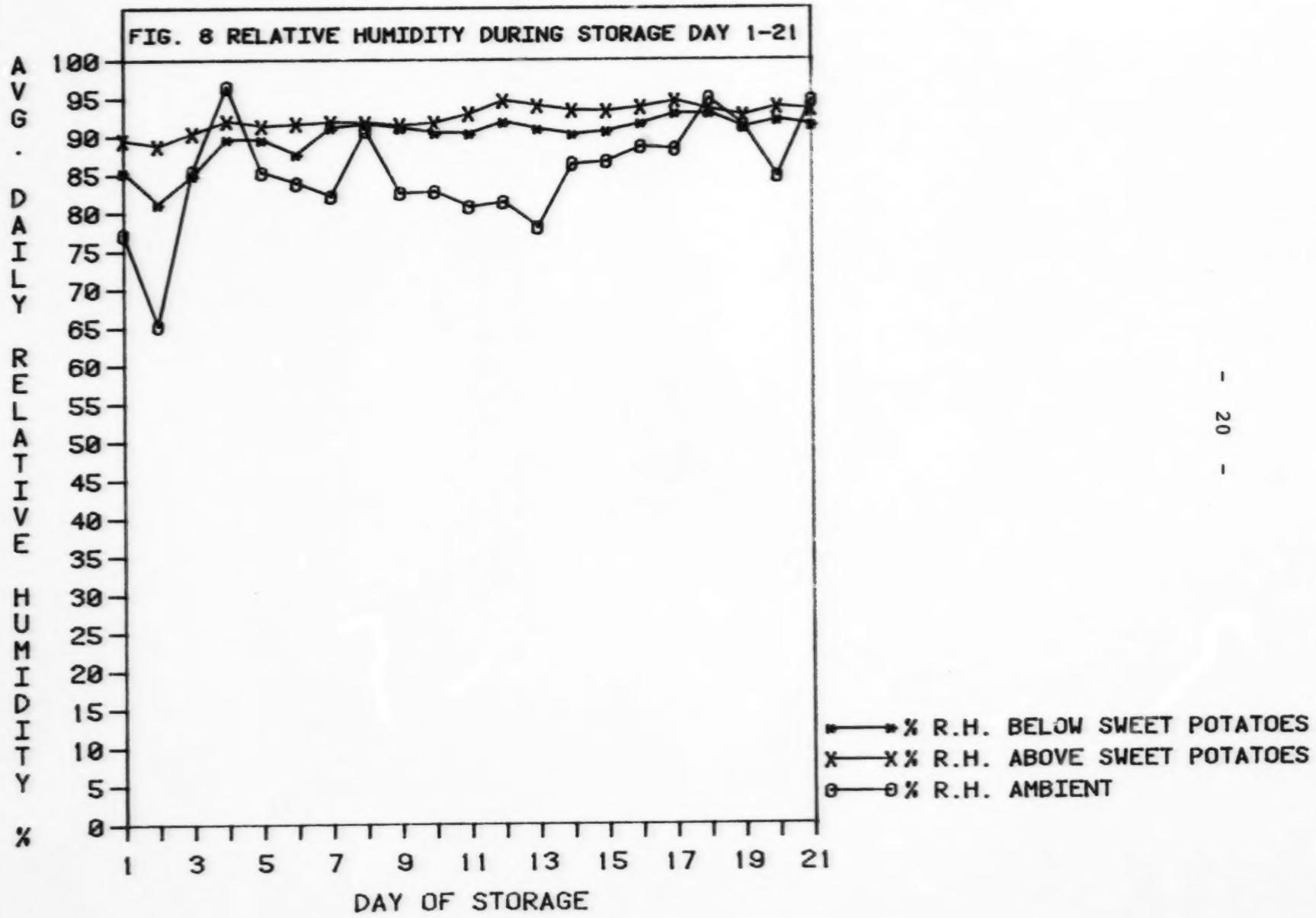
FIG. 8 RELATIVE HUMIDITY DURING STORAGE DAY 1-21
AVG. DAILY RELATIVE HUMIDITY %
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
1
3
5
7
9
11
13
15
17
19
21
DAY OF STORAGE
% R.H. BELOW SWEET POTATOES
% R.H. ABOVE SWEET POTATOES
% R.H. AMBIENT

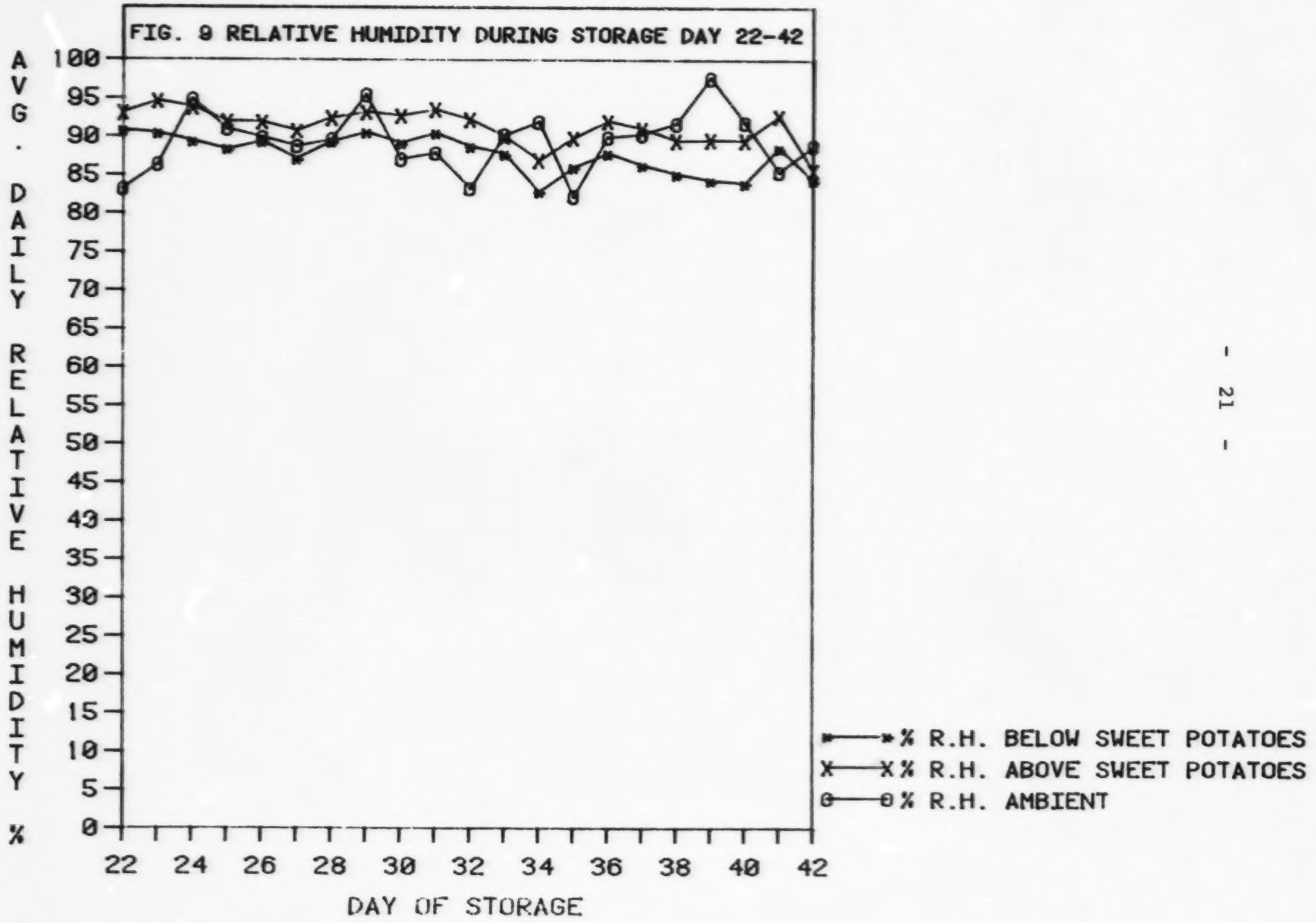
FIG. 9 RELATIVE HUMIDITY DURING STORAGE DAY 22-42
AVG. DAILY RELATIVE HUMIDITY %
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
22
24
26
28
30
32
34
36
38
40
42
DAY OF STORAGE
% R.H. BELOW SWEET POTATOES
% R.H. ABOVE SWEET POTATOES
% R.H. AMBIENT

APPENDIX I: **Predicting Condensation on Roof Surface (Theoretical)**

assume: temperature difference between ambient and storage during the months of January and February is greater than the temperature difference between ambient and curing during the months of September and October.

- storage temperature 13°C @ 90% RH, dewpoint under these conditions 12°C.
- minimum ambient temperature expected during storage -18°C (Delhi).
- an application of 90 mm of urethane foam to the underside of the bulk kiln roof will prevent condensation.

Temperature gradients through roof materials with a 90 mm application of urethane foam:

Layer	RSI	°C/unit of RSI*	Temp. at Plane
outside air layer	0.03	0.20 ambient	-18.0°C
sheet metal roofing	0.11	0.73	-17.8°C
expanded polystyrene (25mm)	0.67	4.45	-17.1°C
aspenite (10mm)	0.12	0.80	-12.6°C
urethane foam (90mm)	3.63	24.10	-11.8°C
inside air layer	0.11	0.73	12.3°C
total RSI =	4.67	storage temp.	13.0°C

*°C/unit of RSI = (13°C -(-18°C) /4.67 RSI) x RSI of material
= (6.64°C/RSI) x RSI of material

Thus, an ambient temperature of -18°C causes a 12.3°C inside wall temperature. Since that is above the dew-point temperature of 12.0°C, no condensation will occur when the ambient temperature is -18°C or warmer.

APPENDIX II: **Heating Requirements**

Known: - proposed curing temperature, 30°C
- proposed storage temperature, 13°C
- kiln insulation values - roof, 4.67 RSI
- wall (2), loading doors, burner wall (1), 2.11 RSI
- hot air delivery plenum, 1.05 RSI
- surface area - roof, 37.2 m^2
- wall (2), loading doors, burner wall (1), 66.0m^2
- hot air delivery plenum, 10.8 m^2
- perimeter of hot air delivery plenum, 30.5 m
- sweet potato heat of respiration @ 25°C 577 - 780 J/kg.h
- sweet potato heat of respiration @ 15°C 208 - 257 J/kg.h
- sweet potato air exchange requirements, 1.4 m^3/(1000 kg.h)
- assume minimum expected outside design temperature during storage (mid - February), -18°C
- maximum storage of sweet potatoes, 22 tonne
- minimum storage of sweet potatoes, 11 tonne

Estimated Heat Loss Per hour

$Qc = U \times A \times \Delta T$

where Qc = heat transfer through kiln material, Watt (W)
U = overall heat transfer coefficient, W/(m^2. °C)
A = exposed surface area, m^2
ΔT = temperature differential between inside and outside °C

Roof $Qc = 0.21 \times 37.2 \times (13 - (-18))$
$= 242$ W

Walls (2), Loading Doors, Burner Wall (1)

$Qc = 0.47 \times 66.0 \times (13 - (-18))$
$= 962$ W

Hot Air Delivery Plenum $Qc = 0.95 \times 10.8 \times (13 - (-18))$
$= 318$ W

Perimeter $Qc = P \times F \times \Delta T$
P = building perimeter, m
F = perimeter heat loss factor, 1.42 W/(m. °C)
$Qc = 30.5 \times 1.42 \times (13 - (-18))$
$= 1343$ W

APPENDIX II: **Heating Requirements Ctnd.**

Total Heat Transfer $Qc = 242\ W + 962\ W + 318\ W + 1343\ W$

$= 2865\ W$

Heat Loss Through Air Exhange $Q_A = 0.373 \times \Delta T \times AE$

Q_A = heat loss through air exchange,

0.373 = constant representing the heat content of air

AE = air exchange per hour, m^3

@ maximum storage of 22 tonne, $Q_A = 0.373 \times (13 - (-18)) \times (1.4\ m^3/t.h) \times 22\ t = 356W$

@ minimum storage of 11 tonne, $Q_A = 0.373 \times (13 - (-18) \times (1.4\ m^3/t.h) \times 11\ t = 178W$

Total Heat Loss $Q_{th} = 2865W + 356W$

$= 3221W$ @ 22 tonne stored

$Q_{th} = 2865W + 178W$

$= 3043W$ @ 11 tonne stored

Heat Gain Through Respiration of Sweet Potatoes

$Q_{HG} = (208J/kg.h) \times 22{,}000\ kg$

$= 4.58\ MJ$ or $1272W$ @ 22 tonne stored

$Q_{HG} = (208J/kg.h) \times 11{,}000\ kg$

$= 2.29\ MJ$ or $636W$ @ 11 tonne stored

Total Heating Requirements

@ maximum storage of 22 tonne, heating requirements

$= 3221W - 1272W$

$= 1.95\ kW$

@ minimum storage of 11 tonne, heating requirements

$= 3043W - 636W$

$= 2.41\ kW$

Therefore, maximum heating load is when 11 tonnes of sweet potatoes are stored at 13°C with a minimum outside temperature of -18°C. Heating requirements are 2.41 kW. Thus, a 4.8 kW should be sufficient for this application.

APPENDIX III: Cooperator's Curing and Storage Log

	Date	Time	Thermostat Setting	Opening of Fresh Air Intake Damper	Length of Time Water Added
Curing Start	Sept. 26	5:30 p.m.	30°C	0.5 cm	30 minutes
	27	4:30 p.m.	30°C	0.5 cm	---
	28	11:30 a.m.	30°C	0.5 cm	10 minutes
	29	2:30 p.m.	30°C	0.5 cm	---
	29	6:00 p.m.	30°C	2.5 cm	---
	29	8:30 p.m.	30°C	4.0 cm	---
	30	7:30 a.m.	30°C	10.0 cm	---
	30	1:00 p.m.	30°C	5.0 cm	---
	Oct. 1	7:30 a.m.	30°C	0.5 cm	---
	2	7:30 a.m.	30°C	0.5 cm	20 minutes
	3	8:00 a.m.	30°C	0.5 cm	10 minutes
	3	6:00 p.m.	30°C	0.5 cm	---
Curing End, Storage Start	4	11:00 a.m.	15°C	0.5 cm	---
	5	7:30 a.m.	15°C	2.5 cm	---
	6	7:00 a.m.	15°C	0.5 cm	15 minutes
	7	10:00 a.m.	15°C	7.5 cm	15 minutes
	8	12:00 p.m.	15°C	0.5 cm	---
	8	2:30 p.m.	15°C	0.5 cm	20 minutes
	9	7:30 a.m.	15°C	5.0 cm	---
	10	11:30 a.m.	15°C	2.5 cm	---
	12	8:00 a.m.	15°C	2.5 cm	---
	13	11:00 a.m.	15°C	0.5 cm	10 minutes
	14	2:30 p.m.	13°C	0.5 cm	---
	14	5:30 p.m.	13°C	5.0 cm	15 minutes
	19	11:30 a.m.	13°C	0.5 cm	15 minutes
	21	10:30 a.m.	13°C	0.5 cm	---
	22	1:30 p.m.	13°C	0.5 cm	15 minutes
	23	12:30 p.m.	13°C	0.5 cm	---
	25	1:00 p.m.	13°C	0.5 cm	15 minutes
	26	11:30 a.m.	13°C	1.0 cm	---
	28	11:30 a.m.	13°C	1.0 cm	15 minutes
	30	1:30 p.m.	13°C	1.0 cm	30 minutes
	31	3:30 p.m.	13°C	1.0 cm	20 minutes
	Nov. 2	2:00 p.m.	13°C	0.5 cm	20 minutes
	3	3:00 p.m.	13°C	0.5 cm	---
	4	11:15 a.m.	13°C	0.5 cm	---
	5	1:30 p.m.	13°C	0.5 cm	---
	6	2:15 p.m.	13°C	0.5 cm	20 minutes
	7	8:45 a.m.	13°C	0.5 cm	15 minutes
	9	10:00 a.m.	13°C	0.5 cm	15 minutes
	10	2:00 p.m.	13°C	0.5 cm	15 minutes
	11	10:00 a.m.	13°C	0.5 cm	---
	12	3:00 p.m.	13°C	0.5 cm	30 minutes
	13	1:45 p.m.	13°C	0.5 cm	15 minutes
Storage end	Nov. 14	10:00 a.m.	Off	Off	Off

Figure XI: Sweet Potato Curing and Storage Energy Requirements

	Start	Finish	Period of Time (h)	Heater Consumption (kWh)	Blower Consumption (kWh)	Blower & Heater Cost @ $0.0505/kWh
Curing	Sept. 26	Oct. 4	185.5	820	90	$45.96
Storage	Oct. 4	Nov. 14	983.0	520	490	$51.01
Curing & Storage	Sept.26	Nov. 14	1168.5	1340	580	$96.97

Figure X: Percentage Weight Loss After Curing and Storage

Variety	Grade[1]	Harvest Wt. (kg)	Post-Curing & Storage Wt. (kg)	Weight Loss[2] (%)
JEWEL	Jumbo	228.9	215.2	6.0
	No. 1	515.5	479.0	7.1
	Canners & Culls & Splits	270.1	245.9	9.0
GEORGIA JET	Jumbo & No. 1	178.6	165.7	7.2
	Canners & Culls & Splits	89.1	81.6	8.4
MIXED[3]	Jumbo & No. 1			
	Canners & Culls & splits	174.4	157.8	9.5

Grade[1] Jumbo - diameter greater than 90mm and/or length greater than 230mm

No. 1 - diameter 50 - 90 mm and length 75 - 230mm

Canner & Culls & Splits - diameter less than 50mm and length less than 180mm and/or misshapened or cracked

$$\text{Weight Loss (\%)}^{2} = \frac{\text{harvest wt. (kg) - post curing \& storage wt. (kg)}}{\text{harvest wt. (kg)}} \times 100$$

Mixed[3] - Regal, Resisto, Cordner, Topaz and Sweet Red